CHAPTER FOUR

ENERGY AND TRANSPORTATION

THE U.S. TRANSPORTATION SECTOR REMAINS ALMOST ENTIRELY DEPENDENT ON PETROLEUM. TRANSPORTATION'S OIL DEPENDENCE THROUGHOUT THE DEVELOPED ECONOMIES OF THE WORLD AND GROWING OIL DEMAND IN DEVELOPING COUNTRIES ARE PUSHING THE WORLD TOWARD GREATER RELIANCE ON ORGANIZATION OF PETROLEUM EXPORTING COUNTRIES (OPEC) OIL. ALTHOUGH THERE IS CONSIDERable uncertainty about the future consequences of oil dependence, the United States is clearly becoming more dependent on imported oil. In 1994, U.S. net oil imports came within two percentage points of the historic high of 47 percent of total U.S. consumption in 1977. (USDOE 1995b, 136)

Over the next two decades, transportation is expected to be the principal reason for growing world oil demand.

Transportation energy efficiency (based on energy use per ton- or passenger-mile) in the United States remains stagnant. (Although these are the most commonly used measures of energy efficiency, they overlook changes in the quality of transportation services, such as speed or reliability.) The evidence is now very strong that past programs and initiatives, such as the corporate average fuel economy standards, have had very nearly their full effect and that in the future, transportation's energy demand is likely to grow in step with the growth of ton-miles and passenger-miles. There are some notable exceptions, however, such as rail freight transport, which continues to make impressive efficiency gains.

At the same time that transportation's dependence on imported oil is growing and efficiency improvements have leveled off, new initiatives have been undertaken to foster markets for alternative fuels[1] and vehicles that reduce vehicular air pollution. In response to requirements of the 1990 Clean Air Act Amendments (CAAA), automobile manufacturers and the petroleum industry teamed up to develop cleaner gasoline and diesel fuels. The efforts to develop reformulated gasoline (RFG) and cleaner diesel fuel were novel in viewing vehicle and fuel as a single system and attempting to improve their performance jointly. Despite some initial start-up problems, the RFG program was successfully implemented. By the end of 1995, RFG accounted for about one-quarter of U.S. gasoline demand. RFG followed on the heels of cleaner diesel fuel, introduced nationwide in 1994.

The 1992 Energy Policy Act (EPACT) and the 1990 CAAA call for more widespread use of alternatives to petroleum fuels (a thrust also supported by the Intermodal Surface Transportation Efficiency Act (ISTEA). With the exception of reformulated gasoline, alternative fuels are still a very minor component of transportation fuels. Yet continued technological advances combined with the experience manufacturers and consumers are gaining with these technologies are making alternative fuels increasingly viable substitutes for gasoline. Alternative Fuel Vehicle Fleet programs prompted by the CAAA and ISTEA as well as EPACT also gained momentum in 1995.

It is important to note that many of the environmental impacts of transportation arise from its use of energy. Burning fossil fuels for transportation produces most of the harmful air pollution from transportation and nearly all of the emissions of greenhouse gases. Production of transportation fuels also can create upstream environmental impacts from, for example, oil spills and leaking storage tanks, and land-use conflicts related to exploration and development of oil fields. These and other environmental impacts associated with transportation energy use are discussed in detail in Part II.

This chapter reviews energy use in the transportation sector. Attention is given to the sector's continued dependence on imported oil and the slowing of energy efficiency gains in recent years. The growth in alternative fuels and vehicles use, prompted by environmental concerns, is also discussed. Finally, historical trends in transportation energy use is examined using Divisia Analysis.

Energy Use

Transportation, including equipment, travel, and freight shipments, is the fastest growing sector of the world economy. It has also been virtually the only growth sector for oil demand over the past 20 years. (World Energy Council 1995) Despite two price upheavals in the world oil market, transportation energy demand grew at an average annual rate of 1.8 percent per year in industrialized (Organization for Economic Cooperation and Development—OECD) economies and at 2.0 percent per year in the former communist economies. But in the developing world, where the greatest potential for growth lies, transportation energy use increased at 4.5 percent per year, despite the effects of oil price increases. Automobile ownership rates in most developing countries are only a small fraction of those in the advanced industrial economies (see chapter 9). Not surprisingly, ownership rates are growing most rapidly in the economies with the fewest vehicles. China and the former Soviet Union, with huge land areas and vast populations, have enormous potential for expansion of highway transportation. Worldwide, freight transport has grown 3 percent annually and air passenger transport 7 percent per year. Over the

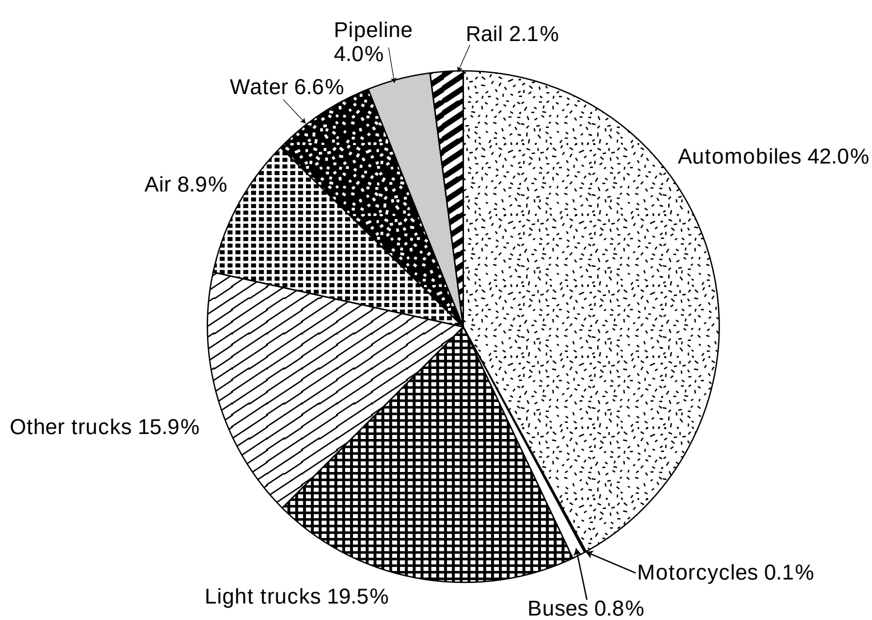
[1] Alternative fuels include methanol, ethanol, natural gas (in either compressed or liquid form), electricity (to power electric vehicles), hydrogen, and reformulated gasoline.

next two decades, transportation is expected to be the principal reason for growing world oil demand.

Highway vehicles continue to dominate transportation energy use and petroleum continues to be the dominant energy source. In the United States, passenger cars use 42 percent of total transportation energy, light trucks 20 percent, and heavier trucks 16 percent. Highway vehicles of all types account for 78 percent of the transportation sector's energy demand (see figure 4-1). Air transport is the biggest energy user among nonhighway modes and the fastest growing mode of all. Pipelines, which amount to 4 percent of total transportation energy use, are the only major mode that does not depend on petroleum as a fuel. Natural gas, used exclusively by natural gas pipelines, fuels 76 percent of pipelines' energy demand. All other types of pipelines (crude oil, oil products, coal slurry, and water) use electric pumps.

In the United States, transportation is the only major energy-using sector that consumes more petroleum today than it did in 1973. This in part arises from the continued growth of transportation, and in part from transportation's continued reliance on oil (see figure 4-2). The oil price shocks of 1973–74 and 1979–80 depressed energy demand but did nothing to shake transportation's dependence on oil.

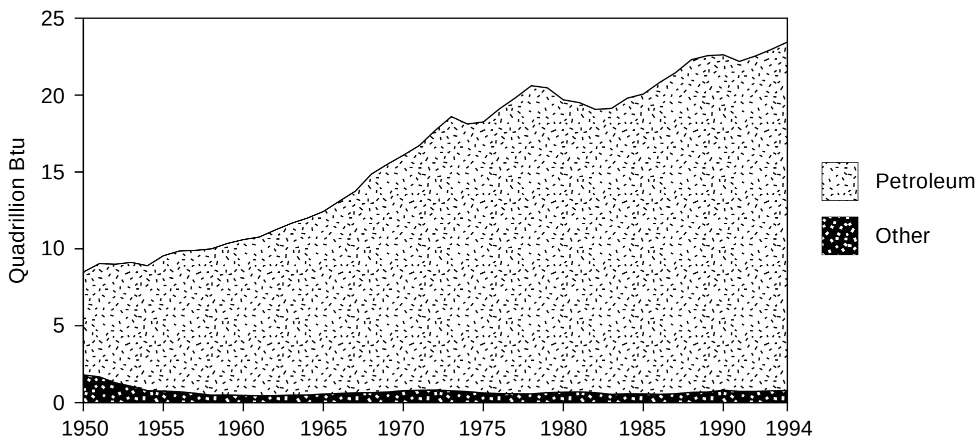
FIGURE 4-1: TRANSPORTATION ENERGY USE IN THE UNITED STATES BY MODE, 1993



NOTE: Does not include off-road motor vehicle use.

SOURCE: S.C. Davis, *Transportation Energy Data Book*, *Edition 15,* ORNL-6856 (Oak Ridge, TN: Oak Ridge National Laboratory, 1995), table 2.10.

FIGURE 4-2: U.S. TRANSPORTATION ENERGY USE, 1950–94



SOURCE: U.S. Department of Energy, Energy Information Administration, *Annual Energy Review 1994,* DOE/EIA-0384(94) (Washington, DC: July 1995), table 2.1.

Oil Dependence

Around the world, oil consumption has been increasing in the transportation sectors of developed countries and in all sectors in developing countries (see figure 4-3). The growing demand for oil is increasingly met by the member states of OPEC. OPEC's share of the world crude oil market increased from a low of 30 percent in 1985 to 43 percent in 1994 and the first half of 1995. (USDOE 1995g) By 2000, the Energy Information Administration (EIA) projects that petroleum consumption could rise from its present level of 67 million barrels per day (MMBD) to 77 MMBD, and that OPEC's share could rise to 46 percent.[2] (USDOE 1995f) By 2010, world consumption is likely to grow to about 90 MMBD, of which OPEC is expected to supply more than 50 percent. (USDOE 1995e) This would give OPEC members a share of the world market equal to that which they held in 1973.

OPEC countries hold the majority of the world's oil reserves—66 to 77 percent of the world's proven reserves of crude oil (the range being due to uncertainty about the reserves of the former Soviet Union. (USDOE 1995d) Proven reserves are those recoverable at current prices using current technology. Considering as yet undiscovered reserves, the U.S. Geological Survey estimates that OPEC countries probably have 55 percent of the world's remaining 1.6 trillion barrels of "ultimate resources" of petroleum.[3] (Masters et al 1994; OPEC Secretariat 1995) Today, OPEC nations are producing at a rate of about 1 percent of their ultimate resources per year. The rest of the world is drawing down reserves at twice that rate. Unless these relationships are changed in a fundamental way, it seems inevitable that OPEC's market share and market power will expand.

[2] EIA defines total petroleum supply to include natural gas liquids, other liquids, and refinery gain, as well as crude oil. In 1993, e.g., crude oil production was 60.1 MMBD, natural gas liquids production came to 5.2 MMBD, and total world petroleum supply was estimated to be about 1.8 MMBD greater than the sum of the two.

[3] OPEC's own estimates put world undiscovered and discovered reserves at 1.5 trillion barrels, of which they believe they hold 64 percent.

While other sectors of the economy shifted away from oil over the past two decades, the U.S. transportation sector remains almost totally dependent on petroleum. Oil use in residential and commercial buildings declined from just under 18 percent in 1973 to 7 percent in 1994. Over the same period, utility oil use dropped 15 percent, while industrial oil consumption remained about the same, fluctuating between one-quarter to one-third of total energy use (see figure 4-4). The industrial sector's oil consumption remained relatively stable primarily because of the importance of petroleum as a feedstock for the petrochemicals industry.

In 1973, transportation used 17.8 quadrillion Btu (quads) of petroleum products to satisfy 96 percent of its total energy requirements. In 1994, transportation consumed 22.7 quads of petroleum, or 97 percent of its total energy use.

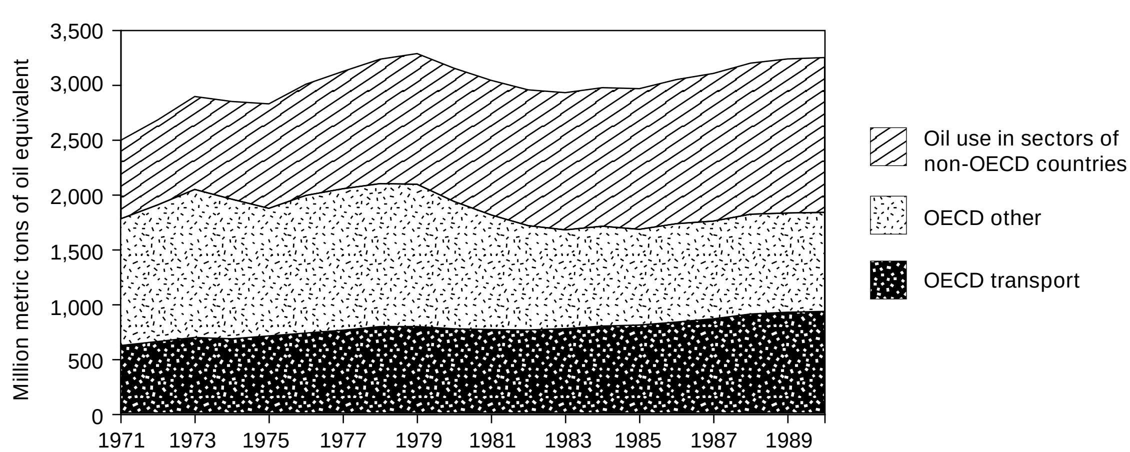
Transportation accounted for 51 percent of U.S. consumption of petroleum products in 1973. Today, transportation accounts for two-thirds of total U.S. oil consumption and more than 80 percent of the light products that drive the petroleum market. (USDOE 1995g)

Growing transportation energy use and continued dependence on petroleum, combined with declining U.S. oil production are increasing U.S. reliance on imported petroleum. In 1973, net imports of petroleum supplied 35 percent of total U.S. consumption. (USDOE 1995g) Dependence on imported oil reached a peak of 47 percent in 1977, then decreased to 27 percent by 1985 as a result of higher oil prices and energy conservation measures. Since the oil price collapse of 1986, U.S. oil import dependence has increased to 45 percent, and EIA projects imported oil will supply about 60 percent of U.S. petroleum demand by 2005.

State of Energy Efficiency Improvements

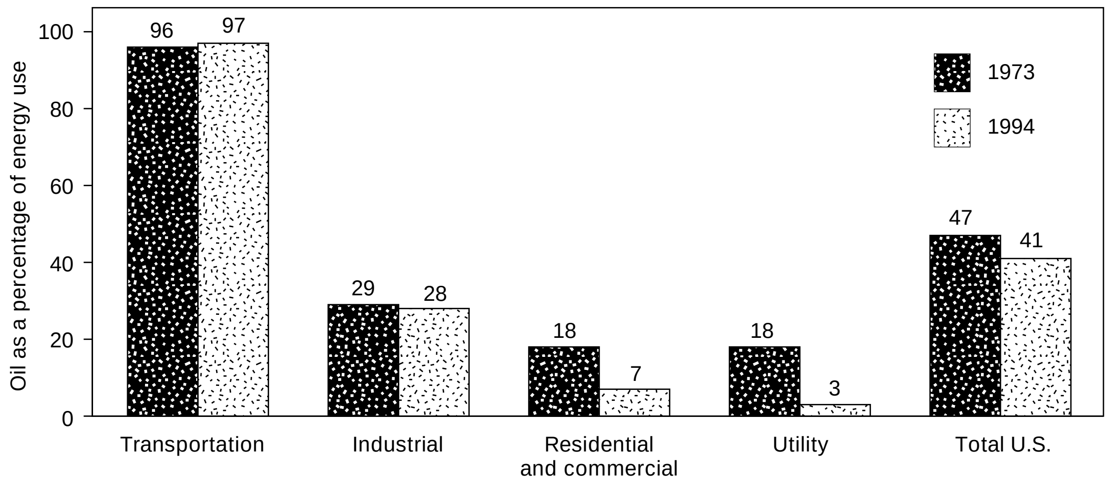
Although it continues to rely on petroleum, the U.S. transportation sector has made significant improvements in energy efficiency over the past 20 years. Since 1990, however, efficiency

FIGURE 4-3: PETROLEUM DEMAND IN THE TRANSPORTATION SECTOR IN OECD COUNTRIES RELATIVE TO OIL USE IN ALL SECTORS OF NON-OECD COUNTRIES



SOURCE: International Energy Agency, 1992.

FIGURE 4-4: PETROLEUM DEPENDENCY OF U.S. ECONOMIC SECTORS, 1973 AND 1994



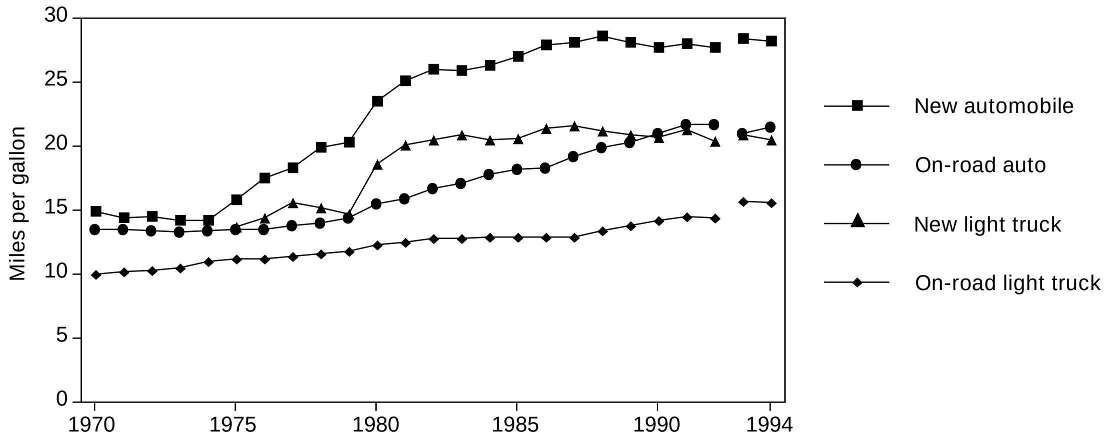
SOURCE: U.S. Department of Energy, Energy Information Administration, *Monthly Energy Review*, DOE/EIA-0035(95/10) (Washington, DC: October 1995).

improvements appear to have tapered off or stopped for the largest energy-using modes. In 1991, transportation energy use was about 15 percent lower than it would have been had there been no changes in modal energy intensities or the modal structure of passenger and freight flows since 1972. (Davis 1995) This remained nearly unchanged in 1992 and 1993 (the latest year for which data are available). The slowing of efficiency improvements is true for all major modes. On-road passenger car fuel economy increased about 60 percent between 1975 and 1994, from 13.5 miles per gallon (mpg) to 21.5 mpg in 1994. (Davis 1995) (See figure 4-5.) From 1991 to 1994, however, there was essentially no change. The cause is easy to find: new car mpg has not increased significantly since 1982.

A somewhat more complex story is told by the data for light and heavier trucks. Fuel economy estimates for all types of trucks are collected by the Bureau of the Census every five years as part of the Truck Inventory and Use Survey. These data allow a comparison of mpg trends by truck model year at three different times—1982, 1987, and 1992. Mpg estimates for single- and multiple-trailer combination trucks are shown in figures 4-6 and 4-7. Both show a gradual trend of improving fuel economy from about 5 mpg in the early 1970s to about 6 mpg by 1990. The fact that mpg seems to improve by model year rather than vary with the calendar year of the survey or the age of the truck suggests that the mpg improvements reflect steady technological advances rather than changes in the way trucks are used. The 1992 survey estimates, however, were lower (by a few tenths of an mpg) for model years 1983 through 1986. This may indicate a change in operating or maintenance practices over the five-year period. Whether improvements slowed after 1991 is not possible to tell from these data.

The Federal Highway Administration 1994 estimates for all combination trucks indicated a slight decline in mpg from 5.7 to 5.6 from 1991 to 1993. The most recent estimates, which are based on a revised method, showing a slight increase from 1993 to 1994, from 5.82 to 5.87. Thus, it is not clear whether heavy-truck fuel

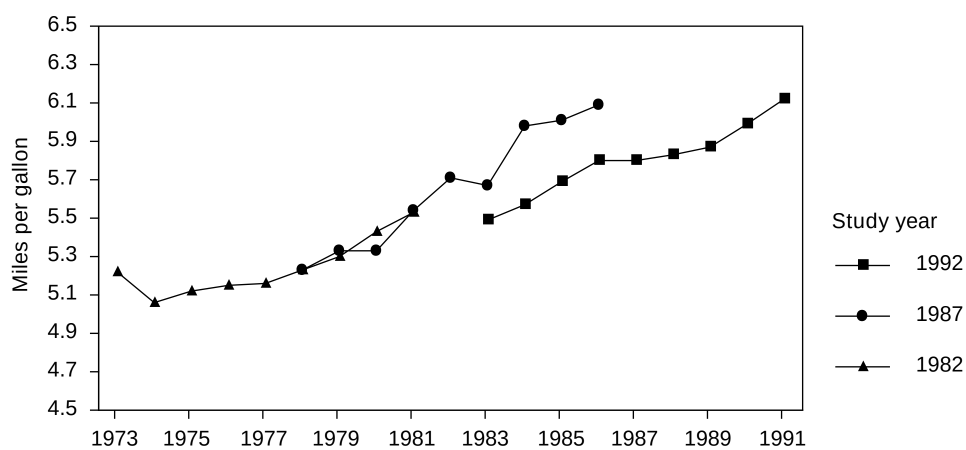
FIGURE 4-5: LIGHT-DUTY VEHICLE FUEL ECONOMY, 1970–94



NOTE: Estimation methods were revised in 1995, making estimates for 1993 and 1994 inconsistent with the historical series.

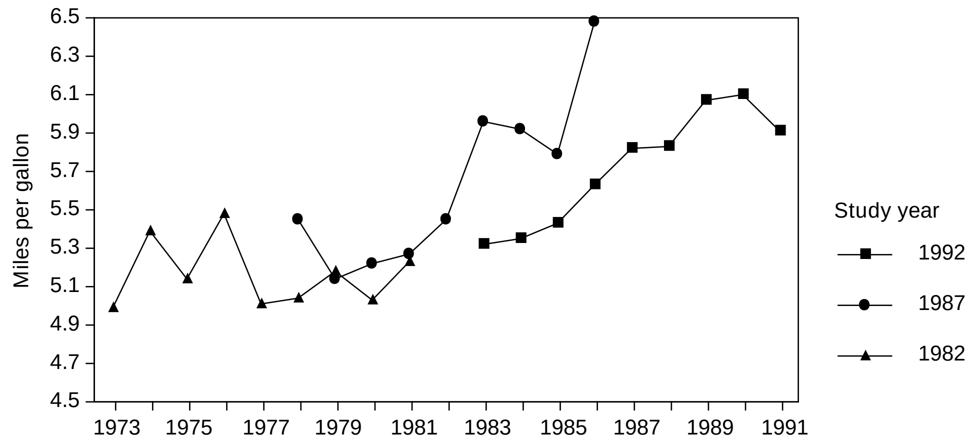
SOURCES: J.D. Murrell et al., Society of Automotive Engineers, "Passenger Car and Light Truck Fuel Economy Trends Through 1980," SAE Technical Series 800853, 1980; J.D. Murrell et al., *Light-Duty Automotive Technical and Fuel Economy Trends Through 1993,* EPA/AA/TDG/93-01 (Ann Arbor, MI: U.S. Environmental Protection Agency, 1993); U.S. Department of Transportation, National Highway Traffic Safety Administration, *Automotive Fuel Economy Program,* 19th Annual Report to Congress, Calendar Year 1994 (Washington, DC: 1995).

FIGURE 4-6: SINGLE-TRAILER COMBINATION TRUCK FUEL ECONOMY, 1973–92 (BY MODEL YEAR)



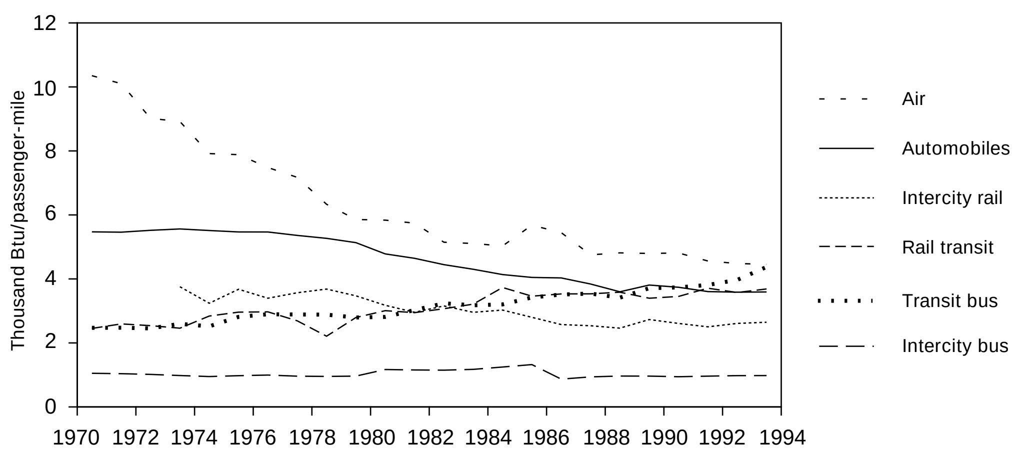
SOURCE: U.S. Department of Commerce, Bureau of the Census, "Truck Inventory and Use Survey," 1982, 1987, and 1992.

FIGURE 4-7: MULTIPLE-TRAILER COMBINATION TRUCK FUEL ECONOMY, 1973–92 (BY MODEL YEAR)



SOURCE: U.S. Department of Commerce, Bureau of the Census, "Truck Inventory and Use Survey," 1982, 1987, and 1992.

FIGURE 4-8: ENERGY INTENSITY OF PASSENGER TRAVEL BY MODE, 1970–93



SOURCE: S.C. Davis, *Transportation Energy Data Book, Edition 15,* ORNL-6856 (Oak Ridge, TN: Oak Ridge National Laboratory, 1995), table 2-15.

economy, which improved by about 20 percent over the past two decades, is continuing to improve or has leveled off.

Trends in energy intensiveness since 1970 reveal three significant phenomena. First, energy per unit of transportation has generally declined, in some cases dramatically (see figure 4-8). For example, the energy intensiveness of commercial air travel was cut by more than 50 percent from 1970 to 1992, falling from 10,351 to 4,482 Btu per passenger-mile. Second, for most modes the rate of improvement in energy efficiency has slowed since the collapse of world oil prices in 1986. Rail freight, however, shows no such deceleration in efficiency gains. Third, dramatic improvements by modes like air passenger and rail freight, combined with increasing energy intensiveness in rail transit and transit bus have produced a convergence of modal energy intensiveness. While substantial differences still remain, modal energy efficiencies differ far less than they did 20 years ago before the first oil crisis. (Davis 1995)

While two or three years are not definitive, the simultaneous stalling of energy efficiency across such dissimilar modes suggests a common cause. The most likely cause is the collapse of oil prices in 1986, when the OPEC cartel abandoned its policy of defending higher prices, and subsequently increased its production of crude oil. The price of oil plummeted; although well above the world oil price before the first price shock of 1973–74, the price was well below the 1974 to 1985 prices (in constant 1987 dollars). (USDOE 1995b, 177)

Motor fuel prices did not change as drastically as oil prices because taxes, refining, and distribution costs comprise the majority of their retail price. Retail gasoline prices, for example, peaked at $2.16 in 1981 (1994 dollars), but are now the same in constant dollars as they were in 1973. Lower prices and stable supplies of oil appear to have signaled the marketplace that further improvements in energy efficiency are not needed.

Efficiency improvements continued well beyond the fall in prices, because of a number of factors including price expectations, government efficiency regulations, the momentum of technological change, and the turnover of the capital stock of transportation equipment. Statistical analyses of oil market responses to price increases and decreases confirm that they have been asymmetric: demand fell more in response to price increases than it rose because of price declines. (Oil demand is perhaps four times as responsive to oil price increases as decreases.) (Dargay and Gately 1994)

If the apparent trend holds up, the stalling of efficiency improvements will mark a significant turning point in world energy markets. The official energy demand projections for OECD countries all assume continued improvements in transportation energy efficiency. The EIA's *Annual Energy Outlook 1995* projects passenger-car and light-truck mpg increasing at the average rate of 1 percent through 2010. Energy use per passenger-mile of air travel is assumed to decline at an average rate of 0.7 percent, while truck and rail freight energy intensities are forecast to decline at about 0.5 percent per year. The International Energy Agency's (International Energy Agency 1994) projections assume similar rates of improvement, as do those of the World Energy Council. (World Energy Council 1995) If these projections prove to be too optimistic, then oil demand will grow more rapidly than expected, as will OPEC's share of the world oil market and, consequently, their market power.

Alternative Fuels

Concerns about the environmental effects of petroleum combustion and the dependence of transportation on oil continue to stimulate interest in alternative fuels. A wide variety of fuels not derived from crude oil are considered alternative or replacement fuels for petroleum under the 1992 EPACT.[4]

At the same time that transportation energy efficiency improvements have stalled, both the use of alternative fuels and the number of alternative fuel vehicles (AFV) are growing. Three

[4] As defined in Section 301 of the Energy Policy Act of 1992 (Public Law 102-486).

federal laws and state and local responses to them are largely responsible for this growth. The 1989 Alternative Motor Fuels Act established a variety of incentives for purchase and use of AFVs and directed federal agencies to purchase AFVs for their fleets.

The CAAA of 1990 required standards for clean fuels, which initially appeared to require the use of alternatives to conventional petroleum fuels. Collaborative research by the automobile and oil industries, however, demonstrated that RFG and diesel fuels could meet the numerical emissions standards specified by the act. The CAAA also allowed the State of California to establish a low-emission vehicle program requiring sales of zero-emission vehicles (for all practical purposes, battery-powered electric vehicles) beginning at 2 percent of all new automobile sales in the year 1998. Other states established a variety of programs encouraging AFVs as a means of meeting their own air quality requirements. As of 1994, at least 13 states have some form of purchase requirements for AFVs in state fleets, and at least 20 have financial incentive programs to promote AFVs. (USDOE 1995c)

In 1992, the EPACT set a national goal of displacement of 30 percent of U.S. petroleum motor fuel use with nonpetroleum fuels by 2010. The EPACT also requires purchases of AFVs by certain covered fleets including federal and state governments, alternative fuel providers, and certain other private fleets to be defined in rulemakings now in progress. A 1993 Executive Order gave the federal government greater responsibility to promote the development and manufacturing of AFVs and increased the federal fleet purchase requirements by 50 percent in 1995 (converging to the original EPACT requirements by 2000) (see table 4-1).

The EPACT requirements and other programs, if carried out, could result in a significant increase in the numbers of AFVs manufactured in the United States and greatly increase the supply and availability of alternative fuels. (USDOE 1995a) Whether the programs will be sufficient to initiate a self-sustaining alternative fuels and vehicles market remains to be seen. If the projections hold up, there will be over 1 million AFVs on the road by the year 2000 and over 5 million by 2005. Although it is not clear which types of AFVs will be selected, it is probable that the mix of vehicles will not be as dominated by a single technology and fuel as today's AFV fleet. Whether AFV plans are pursued as aggressively as the projections indicate depends on advances

TABLE 4-1: FEDERAL GUIDELINES OR REQUIREMENTS FOR PURCHASE OF ALTERNATIVE VEHICLES BY LARGE FLEET OWNERS

Year	Federal	Federal	State	Fuel providers	Private fleets[b]
	EO	required[a]	required[a]	required[a]	
1993	7,500	5,000	—	—	—
1994	11,250	7,500	—	—	—
1995	15,000	10,000	—	—	—
1996	17,500	25%	10%	30%	—
1997	20,000	33%	15%	50%	—
1998	30,000	50%	25%	70%	—
1999	40,000	75%	50%	90%	20%
2000		75%	75%	90%	20%
2001		75%	75%	90%	20%
2002		75%	75%	90%	30%
2003		75%	75%	90%	40%
2004		75%	75%	90%	50%
2005		75%	75%	90%	60%
2006 on		75%	75%	90%	70%

[a] As called for in the Energy Policy Act of 1992, Section 507.
[b] Can be required up to the specified level.

KEY: EO = Executive Order 12844, Apr. 12, 1993.

NOTE: Numbers indicate number of vehicles; percent indicates percentage of fleet purchases.

SOURCE: Adapted from S.C. Davis, *Transportation Energy Data Book, Edition 15,* ORNL-6856 (Oak Ridge, TN: Oak Ridge National Laboratory, 1995).

in technology, especially for battery-powered electric vehicles, and consumer acceptance of AFV technologies and fuels.

The most significant result of the CAAA clean fuel requirements has been the development of cleaner gasoline and diesel fuels. Reformulated gasoline, however, contains significant quantities of nonpetroleum constituents, primarily ethanol and methyl and ethyl ethers. These, in combination with oxygenate use for gasoline in areas where carbon monoxide (CO) emissions are a problem and with ethanol use in gasohol, are creating a significant market for nonpetroleum transportation fuels. The CAAA and EPACT programs are creating a small but rapidly expanding market for alternative fuels and vehicles, generating at least some economies of scale in vehicle and fuel production, and fostering advances in technology. How successful these efforts will prove to be in establishing alternative fuels markets in the United States remains to be seen.

TABLE 4-2: USE OF NONPETROLEUM COMPONENTS IN GASOLINE BY U.S. REFINERIES (THOUSANDS BARRELS[a])

Commodity	1994	Percent	As of Oct. 1995	Percent
Fuel ethanol	3,620	6.2%	8,643	9.4%
Methanol	242	0.4%	246	0.3%
MTBE	52,937	90.5%	79,574	86.2%
Other oxygenates	1,676	2.9%	3,876	4.2%
Total oxygenates	58,475		92,339	
Gasoline produced	2,621,006		2,712,672	
Percent oxygenates by volume	2.2%		3.4%	

[a] 1 barrel = 42 gallons.

KEY: MTBE = methyl-tertiary-butyl-ether.

SOURCES: U.S. Department of Energy, Energy Information Administration, *Petroleum Supply Annual 1994,* DOE/EIA-0340(94)/1 (Washington, DC: 1995), tables 2 and 16; and U.S. Department of Energy, Energy Information Administration, *Petroleum Supply Monthly,* DOE/EIA-0109(95/10) (Washington, DC: October 1995), tables 2 and 28.

Metropolitan areas failing to meet air quality standards for CO have for several years been required to add oxygen-containing compounds, such as ethanol or ethers made from ethanol or methanol to gasoline. The oxygen in oxygenated fuel helps attain more complete combustion, especially during cold months of the year, thereby reducing emissions of CO, a product of incomplete combustion. (Calvert et al 1993; *Automotive Engineering* 1996) Largely as a result of oxygenate requirements for gasoline, use of methyl-tertiary-butyl-ether (MTBE) as a blending component has increased from 100 million to 200 million gallons per year in the early 1980s when it was used solely to enhance octane, to 3.3 billion gallons annually in 1995 (see table 4-2). Production of fuel-grade ethanol, also an octane enhancer (which additionally enjoys an exemption from federal excise tax in some state taxes), has also increased from 80 million gallons annually in 1980 to 2.506 billion gallons in 1995. Most ethanol, however, is blended with gasoline downstream from the refinery to make gasohol. As of October 1995, less than 10 percent of the fuel-grade ethanol produced in the United States was used by refineries to make oxygenated gasoline or RFG. (USDOE 1995h)

The introduction of RFG in January 1995 in response to the clean fuel requirements of the CAAA of 1990 gave additional impetus to oxygenate markets. RFG is required to have an oxygen content of 2 percent by weight, and must also meet limits on vapor pressure and toxic constituents. MTBE and ethanol are the primary nonpetroleum constituents of RFG, but ethyl-tertiary-butyl-ether (ETBE, made from ethanol and butane) and tertiary-amyl-methyl-ether are also candidates. From near zero in December 1994, RFG consumption jumped to almost 2 MMBD in 1995, about 25 percent of total U.S. gasoline consumption in that period (see table 4-3). All but about 15 percent of U.S. RFG demand is satisfied by domestic production.

To date, nonpetroleum components in gasoline constitute a much larger alternative fuels market than that created by all AFVs. RFG (by volume) is comprised of 11 to 12 percent oxygenated components if MTBE is used, 13 to 14 percent if ETBE, and 6 percent if ethanol is the oxygenate. In October 1995, oxygenate inputs to U.S. refineries averaged 3.7 percent of total gasoline product supplied by domestic refineries. In 1995, total use of nonpetroleum constituents in gasoline was expected to amount to about 4.4 billion gallons per year. Because oxygenates have on average about 80 percent of the energy content of gasoline, on a gasoline energy equivalent basis this is about 3.5 billion gallons. This is nearly 10 times the estimated 370 million gallons of gasoline equivalent alternative fuels used by all AFVs in the United States in 1995. (USDOE 1995g[5])

Table 4-3: U.S. Refinery Net Production of Gasoline by Type (million barrels per day)

Type of gasoline	1994	1995
Conventional gasoline	5.93	4.89
Reformulated gasoline	0.24	1.99
Oxygenated	1.43	0.91
Total	7.60	7.79

NOTE: 1995 does not add due to rounding.

SOURCES: U.S. Department of Energy, Energy Information Administration, *Petroleum Supply Monthly,* DOE/EIA-0109(96/02) (Washington, DC: February 1996), "U.S. Year-to-Date Supply, Disposition, and Ending Stocks of Crude Oil and Petroleum Products, January-December 1995"; and DOE/EIA-0109(95/02) (Washington, DC: 1995), table 3, "1994: Products Supplied."

Historical Trends in Transportation Energy Use

When examining any subject in detail there is always the danger of losing sight of the big picture. What are the predominant trends in transportation energy use? Are conditions improving or worsening, and why? This section examines the gross trends in energy use by transportation between 1972 and 1993 with the aim of providing a better understanding of the underlying factors.

The analysis relies on a straightforward mathematical technique called Divisia Analysis, an approach discussed in greater detail in the *Transportation Statistics Annual Report 1995.* (USDOT BTS 1995) The approach makes it possible to decompose trends in a single variable, such as total energy use, into changes in activity levels, changes in the mix of activities, and changes in energy use per unit of activity of each type. Assuming accurate data, the approach makes it possible to assess how much of the change in energy use, for example, is due to the growth of transportation activity, shifts in the modal structure of transportation, and changes in energy efficiency (energy use per passenger- or ton-mile).

Gains in energy efficiency have been much smaller than expected, on the order of 15 to 20 percent for the transportation sector. As a result, transportation energy use was 45 percent higher in 1994 than in 1970. Most of the efficiency gains come from improvements in energy use per vehicle-mile for passenger cars, light trucks, and aircraft. Improved load factors have been key to the enormous efficiency gains of rail freight and commercial air passenger traffic, but declining vehicle occupancy rates have worked against efficiency gains in highway travel. In general, changes in modal structure have played a lesser role but the trend has been toward the more energy-intensive modes.

[5] Singh and McNutt (1993) have taken the analysis a step further to consider all petroleum inputs to the production of oxygenate feedstocks. They find that the total oil requirements for MTBE-based RFG are about 10 percent lower than those of conventional gasoline.

► What Is Divisia Analysis?

The Divisia technique is a mathematical method for analyzing and allocating changes in a variable over time into changes in other variables of which it is composed. For Divisia Analysis to be appropriate, the variable to be analyzed must be expressed as the sum of products of its components. For example, total transportation energy use can be expressed as the sum of the energy use of the various modes of transport. The energy use by any mode can be expressed as the product of its activity level and the rate of energy use per unit of activity. For example, passenger car energy use equals vehicle-miles traveled multiplied by the average number of gallons consumed per mile (the inverse of mpg).

The design of the Divisia Analysis depends partly on the nature of the phenomenon to be analyzed and partly on the data. For example, passenger car energy use can also be expressed as the product of three factors: (passenger-miles) x (passenger-miles/vehicle-mile) x (gallons/vehicle-mile). In this case, the Divisia method can measure the effect of changes in vehicle occupancy, as well as changes in modal structure and vehicle efficiency. Energy trends can be analyzed in somewhat greater detail than emissions (see box 4-1).

When energy trends for the entire transportation sector are analyzed, passenger and freight activity are measured in dollars of expenditure. For separate analyses of passenger and freight modes, the more natural units of passenger-miles and ton-miles are used. Although information on vehicle occupancy rates and load factors is often of uncertain quality, it is judged to be reasonably accurate for discerning trends in all areas except truck freight. Air passenger load factor estimates are very accurate. Thus, it is useful to examine energy trends at the level of individual modes in order to see how efficiency trends and load factors have influenced total energy use. Energy

Box 4-1: How To Interpret the Divisia Method Figures

The mathematical technique known as Divisia Analysis is used here to identify the changes in total transportation energy consumption arising from:

- growth in transportation activity (e.g., passenger-miles, ton-miles, and vehicle-miles traveled);
- changes in rates of transportation energy consumption per unit of transportation activity; and
- changes in the structure of transportation activity (e.g., the relative share of activity by mode).

The results of Divisia Analysis are shown in the figures in the section on Energy Trends. Each figure has two lines: the "actual" line showing total transportation energy consumed and the line showing energy use if 1972 conditions had continued. The difference between the lines is the net effect of changes over time in rates and modal structure. The bars in the figures show how much changes in rates and modal structure contributed to the net effect in a given year. Bars above the horizontal axis push the actual line upward by an amount equal to the length of the bar, while the bars below the axis pull the actual line down by an amount equal to the length of the bar. For example, in 1993 improvements in energy efficiency saved 4.3 quads, while shifts to more energy-intensive modes tended to increase energy use by 0.9 quads. Hence, the net effect was to improve energy efficiency by 3.4 quads compared with what it otherwise would have been had 1972 conditions continued.

For the included factors, Divisia Analysis shows only how much the factor contributes to the transportation trend and not what causes the factor itself. The Divisia method is a tool for dissecting transportation trends over time and suggesting areas for further study. In addition to energy use, Divisia Analysis also can be used to examine changes in emissions from transportation (see chapter 7).

trends are examined in six different categories: 1) total transportation, 2) passenger travel, 3) freight transport, 4) highway passenger travel, 5) air passenger travel and, 6) rail freight. Because key data items for 1994, including air passenger-miles, were not available at the time of writing, the energy Divisia Analysis extends only through 1993.

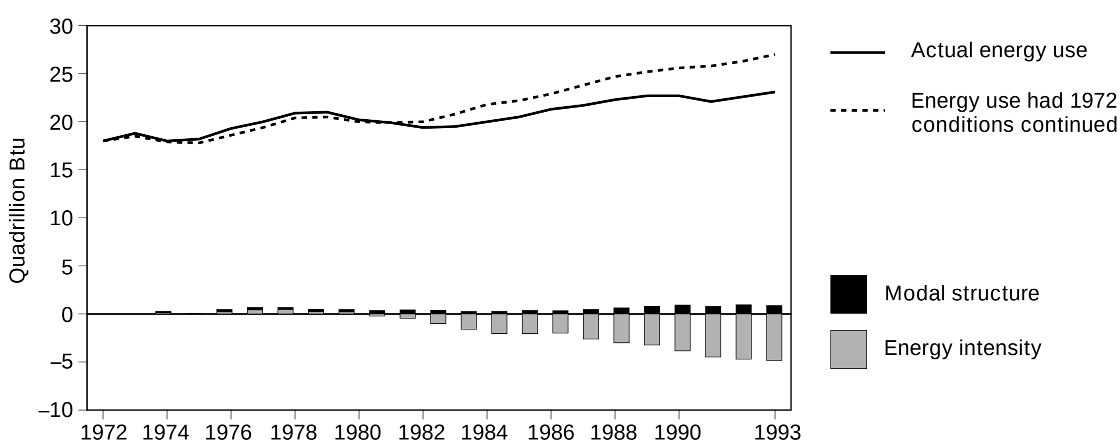
► Energy Trends

From 1972 to 1993, transportation energy use increased by 28 percent at an average annual rate of 1.3 percent per year. Oil price shocks in 1974, 1980, and 1991 caused the only periods of decreasing energy use (see figure 4-9). The trend line projects energy use had no change occurred in energy use per dollar of transportation expenditure. Efficiency improvements and changes in modal structure also had an effect.

Energy use attributed to changes in the modal structure of transportation in the United States increased slightly from 1972 through 1993: the cumulative effect over the past two decades was less than a quadrillion Btu (about 4 percent). Changes attributed to energy intensity measured in passenger- and ton-miles within modes, however, reduced energy consumption with a cumulative effect over 20 years of 4.8 quads (just over 20 percent). Modal energy intensiveness increased until 1977, even though the first oil price shock began late in 1973. The four-year delay shows that it takes time to change the capital stock of transportation vehicles. The combined, cumulative effect of changes in energy intensity and modal structure through 1993 reduced transportation energy use by 4 quads, or about 17 percent (see figure 4-9.)

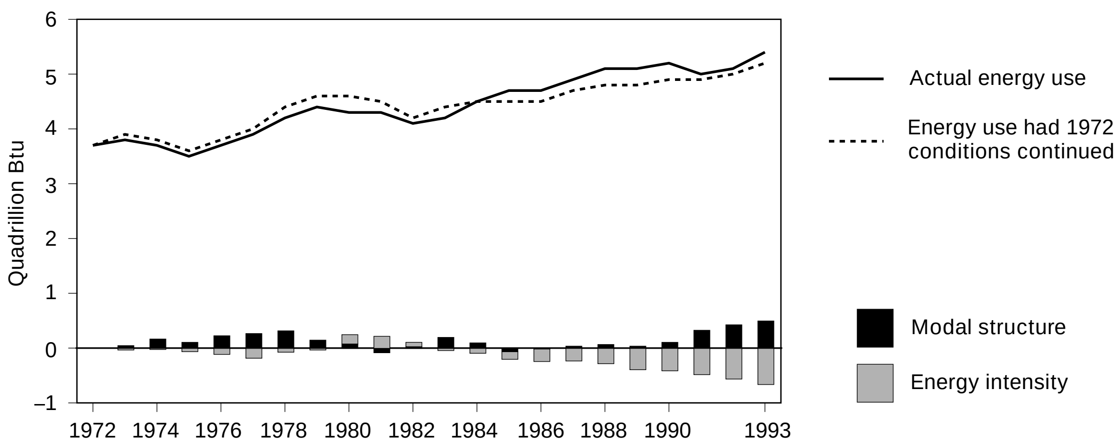
Separate Divisia Analyses of passenger and freight energy use reveal contrasting trends. For passenger travel, the projection showed a 50 percent increase from 1972 to 1993, but the real increase in energy use was only half that amount. Projected freight energy use, on the other hand, is just slightly lower than actual energy use (see figure 4-10). In both cases, changes attributed to modal structure increased

FIGURE 4-9: CHANGES IN TRANSPORTATION ENERGY USE, 1972–93



SOURCE: S.C. Davis, *Transportation Energy Data Book*, *Edition 15,* ORNL-6856 (Oak Ridge, TN: Oak Ridge National Laboratory, 1995), table 2.18.

FIGURE 4-10: CHANGES IN FREIGHT TRANSPORTATION ENERGY USE, 1972–93



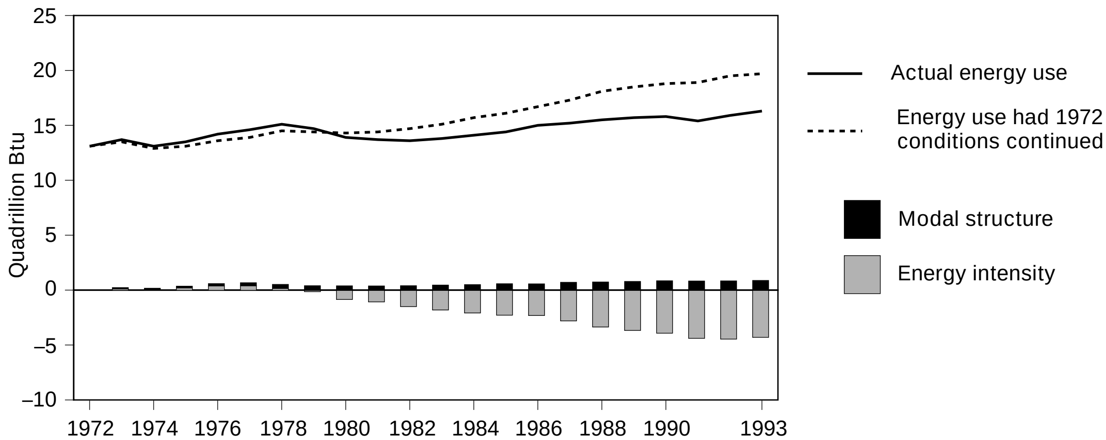
SOURCE: S.C. Davis, *Transportation Energy Data Book*, *Edition 15,* ORNL-6856 (Oak Ridge, TN: Oak Ridge National Laboratory, 1995), table 2.22.

energy use. For freight, shifts to more energy-intensive modes, such as highway and air, outweighed within-mode efficiency gains. In the case of passenger travel, modal efficiency gains, notably in air and highway travel, outweighed structural effects by almost 5:1. It may be significant that energy efficiency gains in all modes of passenger transport, which had been increasing every year since 1977, decreased in 1993 (see figure 4-11). It is premature to call this a trend, but it agrees with other indicators that the energy efficiency of transportation in the United States is no longer improving.

The Divisia Analyses for highway and air transport break out vehicle efficiency gains from changes in occupancy, or load factor (see figures 4-12 and 4-13). The effect of declining vehicle occupancy rates is clearly evident in the highway mode. The Nationwide Personal Transportation Survey (USDOT FHWA 1993) found that the average number of persons per vehicle-mile fell from 1.9 in 1977 to 1.7 in 1983, and again to 1.6 in 1990. This alone accounts for a 20 percent increase in vehicle-miles over the 13-year period. For work trips, vehicle occupancies are approaching the lower bound of 1.0, having declined from 1.3 as recently as 1983, to 1.1 in 1990. In contrast, aircraft load factors (average passenger-miles per seat-mile) have been increasing, as any frequent traveler knows. Whereas experts previously believed that load factors of two-thirds were a practical limit, industry experts now predict load factors in excess of 70 percent after 2010. (Boeing Commercial Airplane Group 1995, Douglas Aircraft Co. 1995) Technological improvements and larger aircraft have been still more important, however, accounting for 70 percent energy efficiency gains of air passenger travel. Had it not been for such gains, air travel would have used more than twice as much energy as it did in 1993: 4.7 quads (instead of 2.3 quads), almost as much as all freight modes combined.

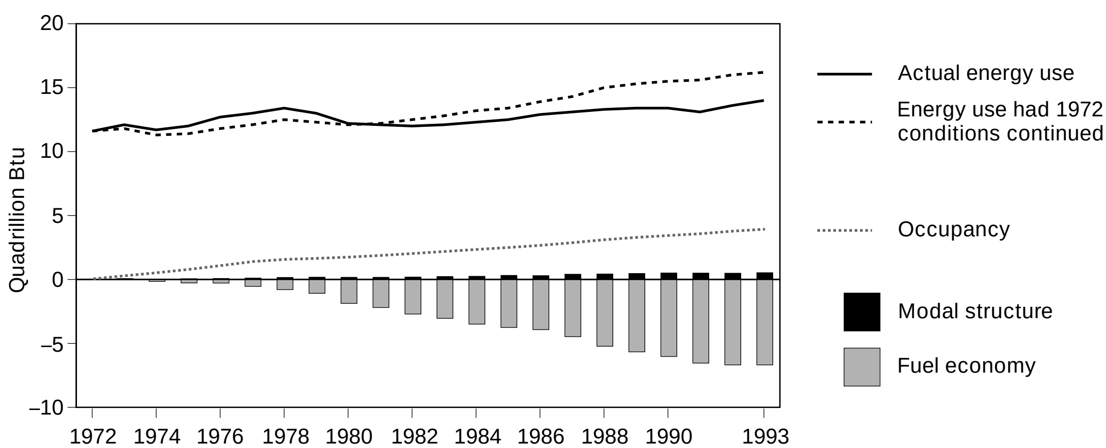
Railroad freight operations also scored enormous efficiency gains, more than halving energy use per ton-mile (see figure 4-14). Unlike the passenger modes, improvements in load factors (ton-miles per car-mile) were the most

FIGURE 4-11: CHANGES IN PASSENGER TRANSPORTATION ENERGY USE, 1972–93



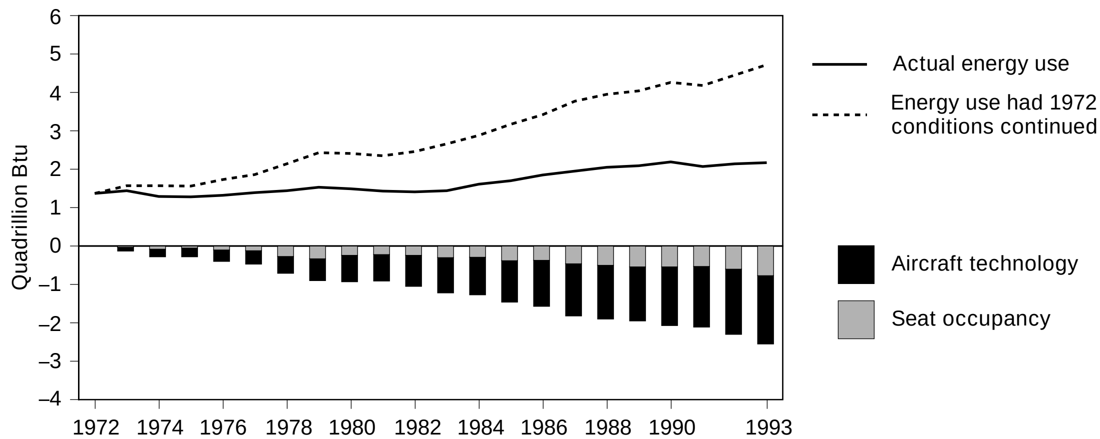
SOURCE: S.C. Davis, *Transportation Energy Data Book*, *Edition 15,* ORNL-6856 (Oak Ridge, TN: Oak Ridge National Laboratory, 1995), table 2.19.

FIGURE 4-12: CHANGES IN HIGHWAY PASSENGER TRANSPORTATION ENERGY USE, 1972–93



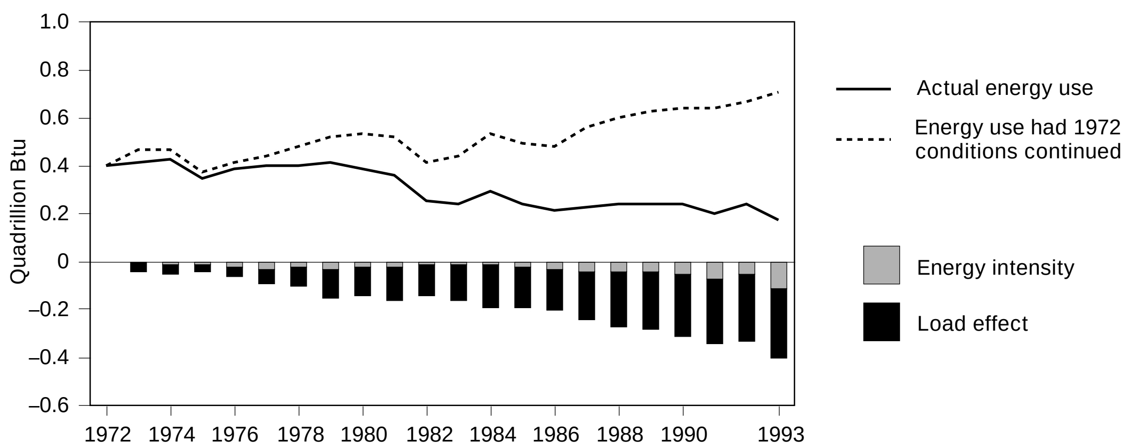
SOURCE: S.C. Davis, *Transportation Energy Data Book*, *Edition 15,* ORNL-6856 (Oak Ridge, TN: Oak Ridge National Laboratory, 1995), table 2.20.

FIGURE 4-13: CHANGES IN AIR PASSENGER TRANSPORTATION ENERGY USE, 1972–93



SOURCE: S.C. Davis, *Transportation Energy Data Book*, *Edition 15*, ORNL-6856 (Oak Ridge, TN: Oak Ridge National Laboratory, 1995), table 2.21.

FIGURE 4-14: CHANGES IN RAIL FREIGHT TRANSPORTATION ENERGY USE, 1972–93



SOURCE: David L. Greene and Yuehui Fan, Transport Energy Efficiency Trends, 1972–1992 (Oak Ridge, TN: Oak Ridge National Laboratory, December 1994).

important factor, accounting for three-quarters of the overall reduction in rail freight energy use. Technical efficiency gains are understated by the Divisia method, which compares current energy use per car-mile with that in 1972. With much greater car loadings, energy use per car-mile should increase. Since this is not taken into account, true efficiency improvements are underestimated.

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